NUTRITION AND ANIMAL AGRICULTURE IN THE 21ST CENTURY: A REVIEW OF FUTURE PROSPECTS

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Abstract

In the 21st century, the global animal agriculture sector is confronted with a spectrum of multifaceted challenges and opportunities. Nutrition assumes a central role in the pursuit of sustainable, efficient, and ethically sound production practices. This comprehensive review delves into the intricate interplay between nutrition and animal agriculture, with a specific focus on future prospects within an evolving landscape. Considering mounting environmental, ethical, and resource-related constraints posed to conventional feed and production methods, this paper critically examines the emergence of innovative nutritional strategies. These encompass the exploration of novel feed constituents, the implementation of precision nutrition techniques, and the integration of sustainability considerations, offering insights into their transformative potential. The review provides a thorough and systematic analysis of the dynamic changes occurring in the field, highlights key challenges and constraints, and provides a discerning glimpse into the future trajectory of animal agriculture. These considerations span diverse dimensions, including regulatory, economic, and consumer factors. By elucidating the contemporary status of nutrition and its pivotal role in shaping the future of animal agriculture, this review endeavours to contribute to the knowledge of researchers, practitioners, and policymakers, thereby fostering a deeper comprehension of the intricate complexities and emerging opportunities in this vital domain.

Key words**: **animal agriculture, nutrition, sustainability, innovation.

INTRODUCTION

Nutrition and animal agriculture are two closely intertwined fields that hold pivotal roles in addressing food security and combatting malnutrition in the 21st century. Extensive research and analysis have been dedicated to examining the intricate relationship between agriculture and nutrition. A plethora of studies have underscored the potential for agricultural interventions to enhance nutritional outcomes (Masset et al., 2012; Kadiyala et al., 2014; Bhavani & Rampal, 2018; Pandey et al., 2016). These investigations have unveiled multiple pathways through which agriculture can influence nutrition, encompassing the production and availability of diverse and nutritious food, income generation, and the empowerment of women (Kadiyala et al., 2014; Girard et al., 2012).

However, despite the growing body of research, there remain noteworthy lacunae in our comprehension of the intricate linkages between agriculture and nutrition (Girard et al., 2012). Numerous reviews have shed light on the limitations and data deficiencies within the existing evidence base, emphasizing the necessity for further exploration to delineate the causal factors and nuanced dynamics of these linkages

(Bhavani & Rampal, 2018; Girard et al., 2012). Moreover, the formidable challenges faced by food and agriculture systems in the wake of climate change and global megatrends underscore the urgency for comprehensive and sustainable approaches to address nutrition and food security (Calicioglu et al., 2019; Cole et al., 2018).

Within the realm of animal agriculture, a growing realization has emerged regarding the imperative to find alternatives to antibiotics for food-producing animals (Hoelzer et al., 2018). The exploration of vaccines as a substitute for antibiotics has gained prominence, underscoring the critical need for safe and efficient alternatives to safeguard animal health and optimize production (Hoelzer et al., 2018). Furthermore, technological advancements, exemplified by electronic olfaction systems, offer the potential to revolutionize feedstuff analysis and animal nutrition (Campagnoli & Dell'Orto, 2013). These innovations hold promise in augmenting the efficiency and effectiveness of animal agriculture, ultimately bolstering the nutritional quality of animal-derived products. In this context, this review paper delves into the evolving landscape of nutrition and animal agriculture, encompassing both the multifaceted linkages between nutrition and agriculture as well as the innovative prospects within the domain of animal agriculture.

2. CURRENT STATE OF ANIMAL AGRICULTURE

Animal agriculture stands as a cornerstone of the global food system, serving as a vital source of protein and indispensable nutrients. Nevertheless, this sector confronts an array of trends and challenges, necessitating careful consideration and strategic interventions to ensure its sustainability and efficiency in the 21st century.

One notable trend in animal agriculture is the growing emphasis on precision agriculture, coupled with the application of big data analytics (Morota et al., 2018). Precision animal agriculture leverages cutting-edge technologies, including sensors and data analytics, to meticulously monitor and manage livestock production systems. This approach empowers farmers to make informed, data-driven decisions concerning animal health, welfare, and productivity. By harnessing the capabilities of big data, precision animal agriculture harbors the potential to optimize resource allocation, enhance production efficiency, and curtail environmental impacts.

Another noteworthy trend in animal agriculture revolves around the exploration of innovative technologies, such as RNA interference (RNAi) (Bradford et al., 2017). RNAi-based technology holds the potential to revolutionize animal health management by precisely targeting specific genes and suppressing their expression. This approach offers promise in mitigating disease threats and reducing the reliance on antibiotics within animal production systems. Nonetheless, the adoption of RNAi-based technology in animal agriculture introduces its own set of challenges, encompassing regulatory considerations and garnering public acceptance.

Sustainability looms as a formidable challenge in the realm of animal agriculture (Hanson et al., 2008). The sector grapples with the daunting task of meeting the surging global demand for animal products while concurrently minimizing its environmental footprint. Livestock production is intrinsically linked to greenhouse gas emissions, land degradation, and water pollution. Tackling these challenges necessitates the widespread implementation of sustainable practices, encompassing the optimization of feed efficiency, the enhancement of waste management protocols, and the promotion of agroecological approaches.

Antimicrobial resistance (AMR) stands as another profound challenge in animal agriculture (King et al., 2022). The employment of antibiotics in livestock production can contribute to the emergence and dissemination of antibiotic-resistant bacteria, posing grave risks to both animal and human health. Effective communication concerning AMR and the practice of antimicrobial stewardship emerges as a critical imperative to raise awareness, advocate for responsible antibiotic use, and mitigate the proliferation of resistant bacterial strains.

Moreover, climate change poses considerable challenges for animal agriculture (Shi et al., 2022). Escalating temperatures, shifting precipitation patterns, and the advent of extreme weather events can exert adverse effects on animal health, productivity, and the accessibility of essential feed resources. To navigate the impact of climate change, it is imperative to develop resilient production systems, implement climate-smart agricultural practices, and champion sustainable land and water management strategies.

3. NUTRITIONAL INNOVATIONS IN ANIMAL PRODUCTION

Nutrition is an integral foundation of modern animal production, propelling the industry toward enhanced animal health, performance, and sustainability.

In the realm of phytogenic products and feed additives, attention has gravitated toward natural feed additives derived from plant sources, including essential oils and capsaicin (Windisch et al., 2008; Gheorghe-Irimia et al., 2022; Irimia et al., 2020). These additives hold promise in boosting animal performance, fortifying gut health, and augmenting disease resistance. Furthermore, advanced feed additives and supplements such as prebiotics, probiotics, organic acids, and exogenous enzymes have emerged as tools to modulate the intestinal microbiota, enhancing nutrient utilization, overall performance, and health in poultry (Yadav & Jha, 2019).

On the other hand, precision nutrition and personalized feeding represent a pivotal stride in animal agriculture, characterized by the tailoring of diets to individualized requirements, genetic traits, and specific production objectives. Leveraging technologies such as sensors, data analytics, and predictive modeling enables real-time monitoring of animal health, behavior, and nutritional needs. This wealth of data facilitates personalized feeding strategies aimed at optimizing nutrient intake while minimizing waste, yielding improved feed efficiency, reduced environmental impacts, and enhanced animal performance and welfare (Shurson et al., 2021).

Additionally, the evaluation of atypical feed ingredients is a growing endeavor involving by-products, waste materials, and alternative protein sources as sustainable alternatives to traditional feed sources, reducing food waste and environmental impacts. Rigorous assessment of the nutritional composition and digestibility of these ingredients is vital for their effective integration into animal diets (Babatunde et al., 2021; Pinotti et al., 2020).

Advances in feed evaluation techniques have led to the development of cutting-edge *in vitro* methods for assessing the nutritional quality of feed ingredients and complete diets. These methods offer rapid, reliable, and practical means to gauge nutrient availability, digestibility, and utilization, resulting in more precise feed formulations and optimized nutrient utilization while reducing the reliance on costly and time-consuming in vivo trials (Zaefarian et al., 2021; Bryan & Classen, 2020).

Exploration of alternative feed ingredients has researchers investigating resources like soybean molasses and extruded linseed to diversify animal diets and enhance nutritional profiles. These ingredients, with their potential benefits in nutrient composition, fatty acid profiles, and overall animal performance, require a thorough evaluation of their suitability, digestibility, and effects on animal health for successful integration into diets (Rakita et al., 2021; Meignan et al., 2017).

The nutritional strategies for animal health are increasingly gaining attention, recognizing the intricate interactions between nutrition, immune function, and animal health. Tailored nutritional strategies are being developed to bolster immune function, enhance disease resistance, and optimize animal health. A profound understanding of the interplay between diet, the immune system, and gut health is essential for targeted nutritional interventions aimed at preventing diseases and optimizing animal well-being (Ingvartsen & Moyes, 2013).

4. FUTURE TRENDS IN ANIMAL NUTRITION

Genetics and breeding represent pivotal determinants in the pursuit of heightened nutrition efficiency within animal production systems. The selection of animals endowed with favorable genetic traits and the deployment of sophisticated breeding methodologies serve as indispensable tools to enhance the nutritional efficiency of animals, thereby culminating in improved feed conversion, growth, and overall productivity. A confluence of research findings and references substantiates the influential role of genetics and breeding in optimizing nutritional efficiency within animal production.

The advent of genomic evaluation systems has wrought transformative changes in the sphere of animal breeding (Wiggans et al., 2011). These systems harness genomic data to more accurately estimate the genetic merit of animals. The infusion of genomic information augments the efficiency of the selection process, engendering swifter genetic advancements and curtailed generation intervals. This revolutionary stride leaves an indelible mark on the enhancement of nutrition efficiency within animal productions.

Genome editing technologies, exemplified by CRISPR, beckon with promising opportunities for genetic refinement in aquaculture and livestock breeding (Gratacap et al., 2019; Tait-Burkard et al., 2018). These technologies furnish the capability for pinpoint precision in animal genome modifications, zeroing in on specific genes associated with nutrition-related traits. Through the judicious editing of genes, it becomes conceivable to amplify traits such as disease resistance, feed efficiency, and nutrient utilization, concomitantly amplifying nutrition efficiency within animal productions.

The annals of animal breeding have borne witness to the invaluable contributions of selective breeding programs (Broderick, 2018; Juárez et al., 2021). By singling out animals endowed with superior genetic traits related to feed conversion, nutrient utilization, and growth, breeders carve a path to the development of populations manifesting superior nutrition efficiency.

The advent of novel animal breeding programs and genetic manipulation techniques augurs the promise of further enhancing the nutritional attributes of animal products.

The sphere of nutrition efficiency in animal productions pivots crucially on feed efficiency, with genetics emerging as a formidable determinant (Eenennaam, 2017; VandeHaar et al., 2016). Genetic selection premised on traits such as residual feed intake (RFI) and feed conversion ratio (FCR) unlocks the potential to pinpoint and breed animals that necessitate less feed to yield an equivalent output. Leveraging the genetics underpinning modern dairy cows, for instance, augments the prospects of continuing to elevate feed efficiency, ultimately conferring economic and environmental benefits.

Nutrigenomics, the systematic exploration of the interplay between nutrition and an individual's genome, unveils profound insights into the genetic underpinnings of nutrient utilization and metabolism within livestock (Nowacka-Woszuk, 2019). A profound grasp of the genetic mechanisms governing nutrient utilization enables breeders to forge targeted breeding strategies for augmenting nutrition efficiency. This enlightenment further informs dietary adaptations aimed at optimizing animal health, production traits, and overall nutrition efficiency.

The quest for innovative feed sources and alternative methods of protein production has garnered substantial attention within the domain of animal production systems. These endeavors are propelled by the overarching objectives of addressing sustainability concerns, diminishing environmental footprints, and satisfying the ever-mounting global demand for animal-derived protein (Aleksandrowicz et al., 2016; Springmann et al., 2016). A corpus of studies underscores the transformative potential of novel feed sources and alternative protein production modalities within the ambit of animal production.

Insects, notably species such as mealworms and housefly larvae, have emerged as an alternative source of protein for incorporation into animal feed (Sogari et al., 2019; Oonincx & Boer, 2012). These arthropods are endowed with a rich protein content and can be cultivated with consummate efficiency, predominantly utilizing organic waste materials, thus endowing them with an environmentally sustainable and resource-efficient profile as a feed option. Empirical research attests that the inclusion of insects in animal diets remains consonant with optimal animal performance and garners favor with consumers (Sogari et al., 2019). Furthermore, the integration of insects into the feed matrix contributes to the circular economy paradigm by transforming organic waste into invaluable protein resources (Oonincx & Boer, 2012).

Historically, animal by-products, such as blood meal and bone meal, have served as notable constituents of animal feed formulations (Lecrenier et al., 2020). These by-products are replete with proteins and proffer a fertile source of essential nutrients for animals. However, their usage has been subject to stringent regulation predicated on concerns surrounding the transmission of diseases. Nevertheless, the judicious and controlled utilization of animal by-products holds the potential to underpin the sustainable production of animal protein (Lecrenier et al., 2020).

Plant-based protein sources, with a particular emphasis on algae and microalgae, have steadily ascended in prominence as alternative feed ingredients (Wang et al., 2021; Altmann & Rosenau, 2022). Algae species harbor an abundant reservoir of indispensable amino acids and can be cultivated with parsimonious resource outlays, casting them as a veritable model of sustainability for animal feed. Furthermore, the incorporation of plant-based protein sources serves to mitigate reliance on conventional feed ingredients, exemplified by soybean meal, a departure that may redound to positive environmental and societal ramifications (Wang et al., 2021; Altmann & Rosenau, 2022).

Explorations into the utilization of unconventional feed ingredients, encompassing leaf meals and co-products stemming from the biofuel industry, are gaining traction (Makkar, 2018). These ingredients beckon with potential as alternative sources of protein, introducing diversification into animal diets and diminishing the environmental footprint associated with feed production. However, further in-depth research is imperative to meticulously assess their nutritional composition, digestibility, and impact on animal performance (Makkar, 2018).

The adoption of novel feed sources and alternative methodologies for protein production in animal production systems carries substantial ramifications for sustainability, climate change mitigation, and food security (Aleksandrowicz et al., 2016; Springmann et al., 2016). These approaches harbor the capacity to curtail greenhouse gas emissions, diminish land use, and ameliorate water consumption entwined with animal production (Aleksandrowicz et al., 2016). Additionally, dietary transitions incorporating alternative protein sources offer salutary health and environmental co-benefits (Springmann et al., 2016).

7. CONCLUSION

In summary, the intricate interplay between nutrition and animal agriculture assumes a pivotal role in addressing the intricate challenges of food security and malnutrition in the 21st century. While substantial research has illuminated the potential of agricultural interventions in improving nutritional outcomes, there exist notable knowledge gaps necessitating further exploration to elucidate the intricate causal factors and dynamics governing these linkages. Furthermore, the evolving challenges posed by climate change and global megatrends emphasize the pressing need for comprehensive and sustainable strategies to address nutrition and food security.

Within the domain of animal agriculture, a multitude of trends and challenges demand a holistic response. Precision agriculture, underpinned by extensive employment of big data analytics, holds the promise of optimizing resource allocation, augmenting production efficiency, and curtailing environmental footprints. Innovative technologies, including RNA interference, present prospects for revolutionizing animal health management, although they entail regulatory and public acceptance considerations. Sustainability remains a paramount challenge, requiring the adoption of ecologically mindful practices, while the issues of antimicrobial resistance and climate change underscore the imperative for vigilant stewardship and the establishment of resilient production systems.

Nutritional innovation in animal production stands as a fundamental pillar for driving progress in animal health, performance, and sustainability. Emerging trends, such as the utilization of phytogenic products, precision nutrition, the exploration of alternative feed ingredients, advancements in feed evaluation techniques, and the investigation of alternative feed sources, offer multifaceted solutions for enhancing animal nutrition. The intersection of genetics and breeding is pivotal, enabling the efficient utilization of resources and the enhancement of overall productivity.

In the pursuit of sustainable protein sources and alternative production methods, insects, plant-based materials, and animal by-products present promising alternatives. These options mitigate environmental impacts, diminish reliance on conventional feed ingredients, and possess the potential to advance the sustainability of animal-derived protein production. A conscientious approach to unconventional feed ingredients and the judicious application of genome editing techniques further enrich the landscape of animal agriculture.

In essence, the convergence of nutrition and animal agriculture points toward a promising trajectory. As we grapple with the multifaceted challenges of the 21st century, these evolving fields proffer invaluable strategies for bolstering food security, ameliorating environmental impacts, and advancing the sustainability of animal-derived protein production. Simultaneously, these efforts enhance the nutrition and well-being of both animals and humans.

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